

THE IMPACT OF ISOLATED VISUAL REPRESENTATION OF A 3D MODEL IN

THE BIM CAVE

A Thesis

by

SWAROCHISA KANDREGULA

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Chair of Committee,	Julian Kang
Committee Members,	Kunhee Choi
	Ann McNamara
Head of Department,	Joe Horlen

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## ABSTRACT

The BIM CAVE (Computer Aided Virtual Environment for Building Information Modeling) system at Texas A&M University enables users to walk through Building Information Models (BIM) created using commercially available BIM software, such as Navisworks, in an immersive virtual reality environment. The current BIM CAVE system synchronizes the position and orientation of the camera within the building information model, and presents the sequence of building assembly process, which is also called 4D construction simulation. Construction industry professionals, who have tested the BIM CAVE system, expressed their wish to browse Mechanical, Electrical, and Plumbing (MEP) components in the model without getting bothered by any obstructions in their line of sight. In order to address that particular issue, this research developed a new BIM CAVE plugin application that can hide some building components from the sight, or make those components transparent, so that users can see other building components of their interest without getting their view blocked. The new BIM CAVE plugin application was then tested for its effectiveness in improving user's understanding of a 3D model. For this test, five construction industry professionals were invited to use the new function of the BIM CAVE and to address their opinions and views about this new function. This test proved that the new BIM CAVE application will have a positive impact in making timely decisions and in issue resolution which can save a lot of time and money.

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## 1. INTRODUCTION

Before the availability of 3D technology Architects and Engineers used 2D drawings to represent a building. It was not the most natural way to view a building as it required multiple views to depict these drawings in 3D. Buildings grew in size and shape as Architects and Engineers became more creative challenging themselves to push their boundaries. Due to this the need for visualization of 3D models has improved tremendously as it makes extraction of information from the model easier. Building information modeling (BIM) is one technology that helps in visualization of 3D models and hence eases information exchange and representation in a much more natural way. BIM can be used and applied at any point in the life of a building. BIM can be used in design, engineering analysis, conflict analysis, cost engineering, scheduling, and budgeting and facility management.

But as technology advanced so did the complexity of the models. 3D models now incorporate all kinds of information inside them; structural, mechanical, electrical, plumbing and other vital information. Although 3D models improve the visualization process, it's not the most natural way. Humans interact with computers in a different way than they do in real world. Immersive virtual reality (IVR) helps in bridging this gap by incorporating a sense of presence in the way things are visualized. Architects will be able to use the immersive nature of the virtual reality to gain a better understanding of both qualitative and quantitative nature of space that they are designing (Bouchlaghem

et al. 2005). The increased field of view in IVR also increases the sense of presence of the user.

The construction process typically requires visualizing spaces mentally. However, this ability to mentally visualize spaces differs from person to person. Due to this inconsistency problems arise from the misinterpretation of plans. Researchers are trying to combine the benefits of BIM and IVR technologies to address these issues. BIM is slowly being adopted by the construction industry and is on the path to being an industry norm. With the benefits IVR offers, combining it with BIM can prove advantageous to the industry as a whole.

### 1.1 Research Problem

With the increasing complexity of buildings a lot of information is being incorporated in to the 3D model and it is getting ever more tedious to extract useful information from it. Commercially available BIM software have the ability to manipulate specific elements of the model to extract relevant information. Previous versions of the BIM CAVE had limited functionalities but still don't possess the ability to view certain components and systems in isolation or to view them without any kind of obstruction in the line of sight. This could be vital to MEP designers and engineers who can focus of MEP systems to visualize them spatially and understand them more in a qualitative way. Figure-1 illustrates the problem in the current version of the BIM CAVE.





Figure 1 Unsynchronized selection in previous BIM CAVE application.

The problem that the current research is trying to address is as follows:

- Existing BIM CAVE's limitation to hide and unhide 3D model elements that might help designers and engineers in their understating of the spatial arrangement and coordination during construction.
- Reduce the gap between the real world and virtual world.

## 1.2 Motivation

Many of the commercially available BIM software allow users to extend the functionalities through the use of Application Programming Interface (API). API acts like a bridge between user's application and the functions of the commercial BIM application. The existing BIM CAVE system only managed to achieve control over the

camera and time lining construction. In the phenomenological study conducted by Karteek (Kuncham 2013) , Texas A& M University, a participant commented - “I personally like when you can make certain elements of a building transparent. So that you might say the majority of what is going on is behind that wall so can you make that wall transparent so that I can see the essence of what I am trying to understand? When we do this with clients and architects in office, they always want something different turned on and off because everybody is looking at it slightly different. So the more you can make the tool adaptable to any possible user the more beneficial it would become.”

Another participant also mentioned that during coordination meetings it would be difficult to keep people focus on the same issue which is being resolved before moving on to the next issue. As different people look at different screens it is hard to make them concentrate on one particular issue.(Kuncham 2013)

By providing this functionality to the BIM CAVE users it is hypothesized that it can prove beneficial to designers and engineers in meetings to coordinate activities. The software running the BIM CAVE system, Navisworks Manage 2012, provides the necessary API to achieve it. This was a major motivation to investigate the benefits of incorporating these functions into the existing BIM CAVE system.

### 1.3 Research Objective

The Research objective is to investigate the effectiveness in visualizing a 3D model by incorporating additional functions like hide, unhide and overriding transparency to the existing BIM CAVE system.

The following tasks will be followed to achieve the objective of the research:

1. BIM CAVE development: software component
2. Validation of the development using a qualitative research methodology

#### 1.4 Limitations

The BIM CAVE that will be developed will only provide the visualization of the 3D models and information retrieval in the commercial application, Navisworks Manage 2012. Because of this limitation it only works with the files that Navisworks supports.

#### 1.5 Thesis Summary

The first chapter of the thesis contains a brief introduction to the research topic. The chapter deals with the use of BIM and virtual reality systems in the construction industry. It also introduces the BIM CAVE Immersive virtual system and addresses its problems. This is followed by research motivation and the objective of the research.

The next chapter details out the existing knowledge in the field of virtual reality in general as well as specific to the construction industry. It also includes information and previous research about existing CAVE virtual systems. It concludes with research about visualizing 4D models in a virtual reality environment.

The third chapter describes the methodology that is used for the research. It is broken down into different stages to investigate the impact of visualizing isolated model in the BIM Cave System.

The fourth chapter deals with the development of the BIM CAVE system in detail.

The final chapter contains the data collection part of the research, which was used to validate the BIM Cave application developed.

## 2. LITERATURE REVIEW

Virtual reality is an experience wherein a person is surrounded by a three dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it (Rheingold 1991). A person inside such a system experiences a sense of self-location and he interacts with it in almost a natural way by turning his head and moving his eyes to view things around him. We as human beings have developed ability to create 3D images in our minds by transforming 2D information and data from images, photographs, plans and drawings (Kasik et al. 2002). Even though this requires a lot of imagination and is a very complex time consuming process, human beings have become really adept at it. Virtual reality helps ease this process by reducing the burden of user's imagination to a fair extent. It tries to represent the information in the most naturalistic way.

Information about a project can be communicated using 2D, 3D or 4D (3D linked to a construction schedule) (Koo and Fischer 2000). Using 3D for visualization purposes is a much more efficient process which results in effective communication of information about the design and schedule of a project prior to the actual construction itself (McKinney and Fischer ).Songer and Diekmann(Songer et al. 2001) were the pioneers to highlight the advantages of using 3D visualization. Data and information from 2D models was extracted and used to develop 3D models for visualization. Construction schedules

were also simultaneously developed to simulate a walkthrough for a group study involving 50 participants having wide range of experiences. The study was conducted by dividing them into 3 groups. It was concluded that using 3D models and walkthroughs resulted in construction schedules with lesser logic errors and missing relationships over 2D drawings.

The exponential rise in technology over the past few decades have brought many ideas close to reality. Shifting from static visualization to depth sight and advances in the area of Stereo Motion has brought virtual reality visualization to its current form today.

VR can be classified into two broad areas:

1. Desktop VR
2. Immersive VR

In a desktop VR the user views and interacts with an image on a traditional computer screen. The user interacts with the system using traditional input devices such as the keyboard, mouse and the monitor. For users who aren't really comfortable with bulky equipment on them, this is reasonable compromise (Issa 1999).

Immersive Virtual Reality (IVR) is a simulated environment that makes a person inside it feel like it is the real world, to a high degree (Psotka 1995). IVR technology has been researched as a tool for education and training purposes and the results have been encouraging. It has been concluded that IVR creates enthusiasm and interest among students and is ideal for the aforementioned purposes. With the help of IVR collaboration and communication among participants can be improved considerably resulting in a better understanding of ideas, concepts and information.

The most widely available forms of IVR are:

- Head Mounted Display
- Goggles and Gloves
- Vehicle Simulators
- CAVE (Computer Aided Virtual Environment)

An enhanced CAVE system has been used for this research to find a solution to the problems faced by the traditional CAVE systems.

## 2.1 CAVE

In 1991 to assist computational scientists in presenting their research the CAVE system was designed at the Electronic Visualization Laboratory (EVL), university of Illinois at Chicago. It made use of high end workstations and large interactive projection screens. It was displayed at SIGGRAPH '92 as a response to a challenge. The CAVE™ system that was implemented was a 10' x 10' x 10' theater made up of rear-projection screens and a down projection for the floor. Sensors were employed to track the movements of the head and the hands. Stereographic LCD stereo shutter glasses are used to separate the alternate fields going to the eyes. This allows the user to get a different image to each eye. Infrared transmitters cause the lens for each eye to stay transparent and switch during the vertical retrace time. These flicker-free images are at 120 fields per second updating the entire process at 60 Hz. For such an advanced system, it was expensive and couldn't project on all six sides. Moreover, it wasn't robust and lacked the ability to document. There was also good amount of light spillage.

Pennsylvania state university's applied research laboratory developed a system similar to the CAVE™. Their synthetic environment applications laboratory (SEA-Lab) has developed the Immersive Projection Display (Shaw 2002). This system utilizes Mechdyne's surround Screen Virtual Reality (SSVR) system. The SSVR is a CAVE-like immersive projection display (IPD), which enables the user to visualize 3D images and simulations on a 1:1 scale. Alternate images adjusted for the left and right eyes are projected on screens to generate the stereoscopic effect. The difference between the CAVE™ and SeaLab's IPD lies in the number and utilization of screens. The CAVE™ system partially surrounds the user and projects images on 3 vertical walls and the floor. SeaLab's IPD completely surrounds the user with four walls of images. This produces a 360 degree horizontal field of view and enables to view models on a 1:1 scale.

The CAVE IVR systems that have earlier been described are run by custom built application which utilized a set of libraries. These systems don't support popular file formats of 3D modeling software applications. Hence a conversion to a format that is supported by these special systems is essential to view the 3D model. For example, Virtual reality modeling language (VRML) is a specific format developed to run files on the StarCAVE, which was developed by SEALabs (DeFanti et al. 2009). 3D models created in various commercially available applications have to be converted to VRML format before viewing them in this CAVE environment. Some of these CAVE systems also have tools to create 3D models in a supported format. A 3D model needs to be converted to a specific format to be used on the CAVE systems. These formats vary from one CAVE system to another. Despite the many advantages of viewing 3D models in these



environments the file conversion process could be a time consuming process and also results in some loss of information. Most of the time, only geometry related information survives the conversion process (Nseir 2012). The BIM CAVE on the other hand runs on commercially available software that offers support for various file formats. This eliminates the daunting task of converting the file formats and loss of BIM information.

## 2.2 4D CAD/ Graphical Construction Simulation

4D CAD may be defined as 3D CAD linked to the construction schedule (Koo and Fischer 2000). Stanford University conducted a study on the effectiveness of 4D construction sequencing on the Walt Disney Concert Hall project. It concluded that by doing so resulted in many positive changes such as refining the employed scaffolding strategy, developing a plan to install the complex ceiling hall, identifying several conflicts well before schedule. It had also resulted in improved communication and reviewing by the group of people who were involved in the study. Another study by Pennsylvania state university on the use of IVR for 4D construction scheduling process resulted in a compression of the schedule by 28%. This was achieved as the participants had developed a better understanding of constructability when inside the IVR system. They were also able to identify out-of sequence activities easily (Whisker et al. 2003). These results show that it is beneficial to employ IVR to develop 4D construction sequences. They also provide the appropriate environment for effective communication as it generates discussions and provides an opportunity to critique each other's plan objectively.

Karteek (Kuncham 2013) for his research adopted a qualitative approach to test the effectiveness of 4D construction sequencing in an immersive virtual environment.

He concluded that using such an environment lead to better spatial perception of the stakeholders of a project eventually resulting in collaborative resolution of issues which might not be the case when done on a single desktop screen. He also noticed effective communication and collaboration between trades to resolve issues related to spatial interference, installation paths and sequence of building elements before going to the site.

### 3. RESEARCH METHODOLOGY

This section describes the steps taken to achieve the research objective and the research techniques employed in this study. Due to the nature of this study, a qualitative research method has been utilized and an explanation of the selection is provided.

This study uses the BIM Cave which has six walls, each of which is made of two LCD screens. Each wall is connected to a central processing unit (CPU). Communication among the computers is achieved by connecting them to a common network via a wired router. The six walls are arranged at an angle of 140 degrees to each other effectively forming a horizontal field of view of 240 degrees for the user. The BIM CAVE has control over the position and orientation of the camera as well as the ability to simulate a 4D construction sequence. The first step is to develop a new BIM CAVE application that retains the above functions and also provides the user with the choice to select, hide, unhide and change the transparency of model items in a 3D model in an immersive virtual environment.

The research methodology has two steps:

- Development of the new BIM CAVE application
- Validation of the development

Details regarding the two steps are provided in the following sections. Also, further details about the changes in the hardware and software components of the BIM CAVE and its deploying it seamlessly in an IVR environment is provided in the next chapter.

### 3.1 Development

The API of Autodesk Navisworks Manage 2012 is used in the development of the software component of the new BIM CAVE application. The BIM CAVE has two custom made applications, the server and the client application, each serving separate function to achieve the desired immersive effect. The current version of the application controls the camera and synchronizes it across all the computers as the user navigates through a model. It can also simulate a 4D construction sequence. The camera control is achieved by obtaining parameters from the server through API and passing the data to the client. The client application then calculates the relevant camera position by subjecting data to a rotational algorithm. After calculation the client's camera position is reoriented to achieve a synchronized panoramic view of the model. The 4D construction is achieved by identifying the class from the API that triggers the required function. When the user clicks a button on the server to execute, for instance, a step forward function in time, a message is communicated to perform the same function on the client.

Due to increase in the complexity of buildings a lot of information is being included in the 3D model as the end users vary from owners, engineers and sub-contractors. An electrical subcontractor at times might find most of the information irrelevant, unhelpful and often obstructive resulting in wastage of time in understanding

the part he's concerned with. So it is essential to provide the end users with the option of editing parts of the model to ease the process of visualization. There are many ways to temporarily modify a model item and this research deals with the ability of the user to hide, unhide and override the opacity of the items.

This was achieved in two steps: 1) developing plugins using the .NET API's of Navisworks Manage 2012 to hide, unhide and override the transparency of the items. 2) Executing these plugins in the server application through automation. Whenever a button is clicked on the server an event is triggered and a message containing information about the same event is conveyed to the client.

### 3.2 Validation

This research aims to study the effectiveness of some new incorporated functions in visualizing a 3D model in an immersive virtual environment and how it helps industry professionals in the decision making process throughout the life of a building. It also aims to highlight the advantages and disadvantages by incorporating such changes. For the purpose of this study, it is highly essential to study human interactions with the BIM CAVE system and obtain feedback.

Qualitative research methodology is used to evaluate the new system. Qualitative research is primarily an inductive process of organizing data into categories and identifying patterns (relationships) among categories (McMillan, J., and Schumacher, S. 2014). It is used when little information exists on a topic, when variables are unknown, and when a relevant theory base is missing or inadequate (Leedy 2013). A qualitative

study can help define what is important- that is, what needs to be studied (Leedy 2013).

Qualitative researchers believe that there may be multiple perspectives held by different individuals, with each of these perspectives having equal validity, or truth (Creswell 2007). The qualitative research technique used for this research is phenomenological study. Phenomenology seeks to understand a person's or persons' perspectives as he, she, or they experience and understand an event, relationship, program, emotion, etc. (Leedy 2013).

The phenomenological study has helped to understand the participant's perception towards the use of analytical tools in the BIM CAVE System. Feedback from these participants helped in determining the effectiveness of the new setup and how it affects the decision making capability of construction professionals. It also identifies the pros and cons of the setup. Semi structured and informal interviews were conducted with the participants as a part of the research methodology. The main advantage of having an extended informal discussion is that the participants will be able to express their opinion in a clearer and descriptive manner.

### 3.3 Research Design

The research design allowed accessing the participant's experience and knowledge about BIM, project planning, and construction to seek out their perception about the effectiveness of analyzing and making temporary changes to a 3D model in immersive virtual reality system such as BIM CAVE. This research relies on the in-depth interviews with carefully selected sample of participants, which is one of the important

criteria in the phenomenological study. A typical sample size for a phenomenological study ranges from 5 to 25 individuals (Creswell 2007). For this study, five individuals were interviewed. The effectiveness of the research methodology is mainly determined by the four underlying parameters such as:

1. The research participants must be subject matter experts (SMEs). SMEs in this case are defined as people with expertise in BIM and have working experience in AEC industry (Architecture Engineering & Construction). The SMEs opinions were valued for their in-depth understanding of their field of expertise and rational perspective.

2. The nature of study indicated that there will be some constraints during the study that could hinder the SMEs from fully experiencing the new setup of the BIM CAVE due to the limited amount of time spent in the BIM CAVE. Moreover, the participants might be hesitant to completely describe their experience about the BIM CAVE during the interview sessions when exposed to a new place surrounded by people. It has been made sure that the participants were given enough time to spend with the BIM CAVE and were made to feel comfortable by engaging them in a general conversation before the start of the interviews.

3. The BIM model visualized in the BIM CAVE system during the interviews were relevant to what the participants had experienced before. This process ensured that the participants spent less time understanding the model and more time focusing on the effectiveness of the setup.

4. The researcher during the interaction with the SMEs had to be collaborative and cooperative. All the four above-mentioned parameters were addressed to make sure the interviews took place without any hindrances.

### 3.4 Data Collection

The data collection methodology used for the phenomenological study was semi structured interviews. The interviews were designed in a way to gain the understanding of the SMEs' perception towards model analysis and editing in an IVR system and its effectiveness in a decision making process. The interviews were designed to be more flexible and informal by asking open-ended questions to SMEs, thus facilitating them to communicate their thoughts on the new setup effectively.

The data collection involved three phases:

#### 1. The Pre-System Introduction Phase

The purpose of this initial phase was to allow the SMEs to share their general experience about the use of BIM in their company and the kinds of advanced visualizing systems they have used or experienced previously. This phase enabled the researcher to understand the SMEs general notion about BIM and use of advanced visualizing systems to view and analyze BIM models.

#### 2. The System Introduction Phase

The research participants were introduced to the BIM CAVE setup during this phase. A brief overview of how the overall system works and technical details about how the separate computers communicate with each other to achieve an immersive



view were explained. The system introduction phase has two main sub phases. First, they were allowed to just view the 3D model in the BIM CAVE by utilizing the previous versions of the server and client applications. The participants were then asked to use the updated versions which allowed them to make changes to the model and analyze them in a limited manner. This phase acted as a basis for the SMEs discussion with the researcher.

### 3. The Post System Introduction Phase

The Post System Introduction phase had a collaborative discussion between the SMEs and the researcher right after the new BIM CAVE application was introduced. This was the last phase of the interview during which the researcher built up an informal conversation with some preplanned open-ended questions to channelize the thoughts of the SMEs. During this phase the interviewer was also able to obtain the pros and cons of the application developed.

### 3.5 Validity and Reliability

Data collection through informal interviews can be accurate as the researcher is certain of the source of the data, the interviewees who are subject matter experts. The interviewees selected for the study had at least five years of experience in AEC industry with an expertise in BIM, project planning, and construction. Typically, findings that emerge from semi-structured interviews can be more accurate and reliable when compared to the findings revealed by the other research methods (Kvale 1996). The informal interactions with the SMEs reduced the amount of misunderstanding and

misinterpretation by the researcher. The semi-structured interviews also facilitated obtaining some divergent perspectives to know about the benefits and limitations of the new setup.

### 3.6 Data Analysis

The data analysis was performed after the phenomenological study containing the interview information from the SMEs. In a typical data analysis part, the researcher will look for common themes from the transcripts of the descriptive interviews conducted.

The theme of interest for this thesis is the effectiveness of the newly incorporated analytical tools in an IVR environment such as the BIM CAVE. The researcher will typically take the following steps after transcribing the interviews (Leedy 2013):

1. Identify the statements related to the topic.

In this step, anything said by the SMEs that describes interaction through editing and analytical tools in immersive virtual environment such as BIM CAVE were identified. It was made sure that the researcher remained unbiased while identifying the statements from the interview transcripts. This step allowed understanding the general perspective of SMEs.

2. Group statements into meaningful units.

The identified statements from each of the interview transcripts were carefully scrutinized and the clearly redundant statements were removed (Moustakas 1994). With the set of non-redundant units of meaning in hand from each of the interviews,

the researcher examined the statements to group them in to meaningful units to extract the essence of the interviews.

3. Seek divergent perspectives.

The interview transcripts were scanned to identify the pros and cons of the new BIM CAVE application with additional functionality.

4. Construct a composite.

In this step, the information collected from the previous steps was used to summarize the overall experience of the SMEs with the new BIM CAVE application. From the overall description of the five interviews conducted, the researcher summarized the effectiveness of utilizing model analyzing and editing tools in an IVR environment such as BIM CAVE as against on a single computer screen.

#### 4. BIM CAVE DEVELOPMENT

The current BIM CAVE setup can be classified as an immersive virtual reality system that runs on a commercial BIM software application, Autodesk Navisworks. It uses multiple Liquid Crystal Displays (LCDs) and because it is configured to increase the sense of perception and deliver an enhanced user experience. The entire software system of the BIM CAVE is built on Microsoft's .NET framework using the API provided by the

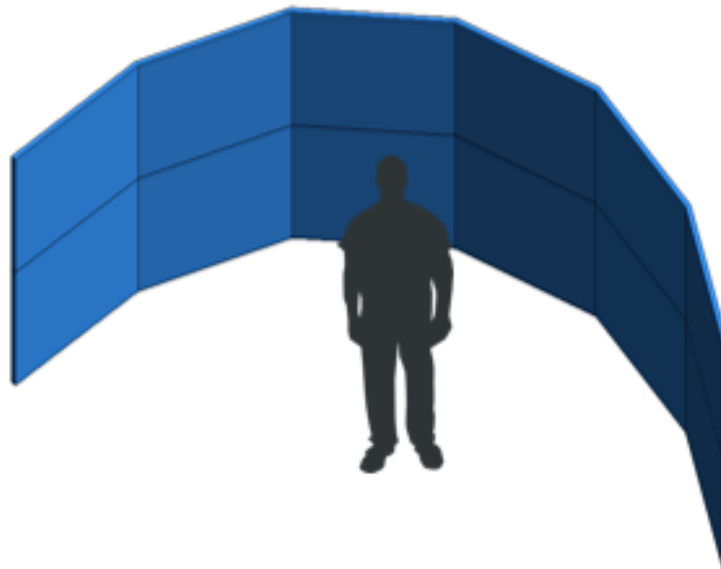


Figure 2 BIM CAVE THFOV: 240 degrees

developers of Navisworks 2012 software. The System provides a Total Horizontal Field of View (THFOV) of 240 degrees as depicted in figure-2. This chapter outlines the hardware and software of the system in detail.

#### 4.1 Hardware Component

The CAVE system used in this research consists of twelve 55" screens and six computers. A wall of screens is formed as each computer is connected to two screens



Figure 3 BIM CAVE: Hardware

and it is configured in such a way that they display one continuous image across them. The screens are connected to the computer using video graphics array (VGA) cables. The computers are equipped with high end i-7 processors and graphics cards. Figure-3 is a photograph of the BIM CAVE hardware.

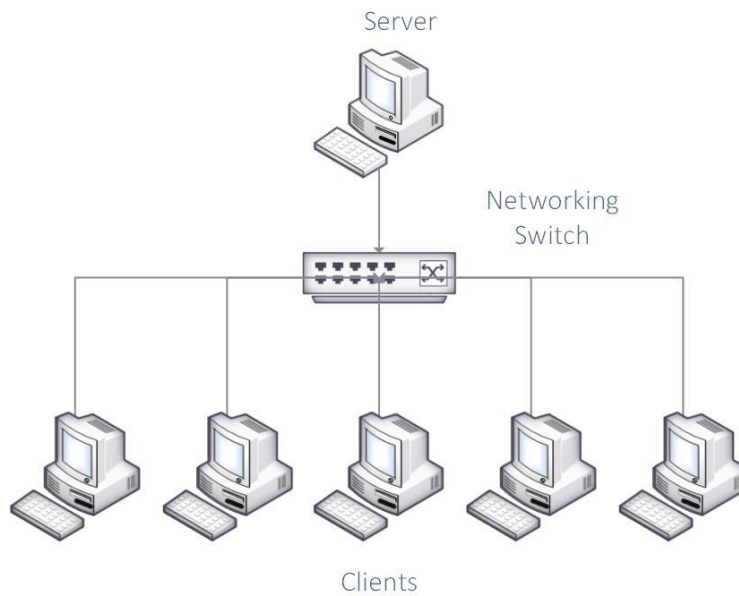


Figure 4 Network configuration of the BIM CAVE

All the computers communicate via a local area network (LAN) which is setup using a wireless networking switch. An illustration of the network can be seen in figure-4. The LAN assigns a unique Internet Protocol (IP) address to each computer for identification during the communication process. The computers use keyboard and mouse as standard input devices.

#### 4.2 Software Component

The BIM Cave software component utilizes both Autodesk Navisworks and a custom made application to produce the desired effect. Navisworks 2012 is the version being used to display the BIM files while the custom made application enables the user control and perform specific functions.

#### 4.2.1 Autodesk Navisworks Manage 2012

One of the most widely used and commercially available BIM software is the Autodesk Navisworks Manage. It not only aids the user in viewing 3D files but also performs complex functions such as clash detection and 4D construction sequencing. In doing so it empowers its users, majority of which are professionals from the construction industry, to achieve real time visualization, 3D coordination and 4D construction simulations.

Advantages of using Navisworks manage 2012:

- One of the most widely used and commercially available BIM software. 3D models are generated from BIM applications such as Tekla, Revit. Navisworks has the ability to support files from many different applications. This removes the additional cumbersome task of converting the 3D model.
- Autodesk provides users with the API that runs on Microsoft's .NET and Component object model (COM) frameworks.
- Autodesk provides a free one-year license for college students to use Navisworks Manage 2012.

#### 4.2.2 Navisworks API

The BIM CAVE application that has been built as a part of this research uses the .Net framework of the Navisworks API. The .Net framework helps developers create applications for Microsoft's Windows operating system.

Previously, Autodesk published the Navisworks API only in the COM framework. But with the 2011 version they extended support to the .Net framework as well.

The .Net API provided by Navisworks can be used for three different purposes.

They are:

1. Plugins: Plugins allow the users to extend the functionality in Navisworks.

Plugins are generally used inside the scope of the main window of the Navisworks application.

2. Automation: Automation is used to drive the application from outside its scope to automate certain tasks and mainly to invoke plugins.

3. Control: Control facilitates to embed an Autodesk Navisworks file viewer in to a custom made application to examine Navisworks documents without having the full application loaded.

The Navisworks .Net API is made of several assemblies that have a wide range of classes, structures, methods and events, which provides access to the application itself. The API mainly has four assemblies that are frequently used.

- Navisworks API Assembly: This is the core API used when working with plugins or with the controls API.
- Automation Assembly: Used when working with automation to drive Navisworks from outside its scope.
- Controls Assembly: Used to access the Navisworks documents within the third party application.
- ComApi Assembly: Used to provide interaction with the older COM API.



The existing BIM CAVE system has achieved control over the camera position and its orientation (Ganapathi Subramanian 2012) and synchronizing the timeline function (Kuncham 2013). This research adds the additional function to view specific model items, which are hidden from the user's line of sight, by either hiding them entirely or making them transparent. For this purpose, Navisworks API assembly and Automation assembly are used among the four for adding the additional functionality to the existing BIM CAVE application.

#### 4.2.3 Developing Plugins

The task of adding functions to the existing BIM CAVE application is divided into sub-tasks. Each of the sub-tasks performs a specific smaller function and eventually contribute in producing the desired result.

The Plugins that need to be developed are as follows:

1. Execute dock pane plugin: Execution of this plugin brings out a selection set list which exists inside the 3D Model. These sets help the user select the model items of his preference.
2. Client selection: It updates the selected items list on the remaining computers with the selection made from selection sets.
3. Hide Selection: Lets the user hide the selection made by him.
4. Hide Inverse: Lets the user hide the model items which are complementary to the selection made by him.
5. Unhide: It makes all the model items visible to the user.

6. Transparency: Enables the user to override the opaqueness of model items.

In order to synchronize the selection of model items over all the computers of the BIM CAVE system it is essential that an ID for each model item be identified. This ID can be used in the communication process between the server and the client.

As the selection is first made in the server the IDs are extracted and sent to the clients.

Once the clients receive the IDs they automatically highlight the model items using them.



Figure 5 Navisworks Add-ins tab displaying executable plugins

These Plugins are built in Microsoft Visual Studio using C# and after building the solution two files are generated under the folder bin\Debug. They are: 1) DLL file, and 2)

Program Debug Database. These files are copied to a folder in the Plugins folder under C:\Program Files\Autodesk\Navisworks Manage 2012 in all the three computers in BIM CAVE system. The name of the folder should match the name of the files generated. This ensures the loading of plugin under Add-Ins tab whenever the Navisworks Manage 2012

application is opened to view a model. Figure-5 shows the plugins in Navisworks Manage 2012 window.

#### 4.3 BIM CAVE Application

The BIM CAVE application version 1.0 was developed by Adithya Ganapathi (Ganapathi Subramanian 2012) as a part of his research to control camera position and orientation of camera. It was updated to version 2.0 by Karteek Kuncham (Kuncham 2013) by adding timelining functionality to it. The BIM CAVE application is developed using the .NET framework in C# language. C# is an object-oriented programming language and its syntax is very similar to the C++ language. BIM CAVE application is made up of Server application which runs in the server computer and Client application which runs in the client computers. The functionalities of these applications are different and are instrumental in rendering immersive virtual reality experience in the BIM CAVE. Server computer controls the central wall of two screens and the client computers control the remaining.

##### 4.3.1 Server Application

It is a standalone executable application that performs specific functions and sends vital information to the clients for synchronization. As previously mentioned version 1.0 achieved camera control and orientation. Version 2.0 managed to perform

timelining functions. This research results in Version 3.0 of the application which lets the user perform the following functions.

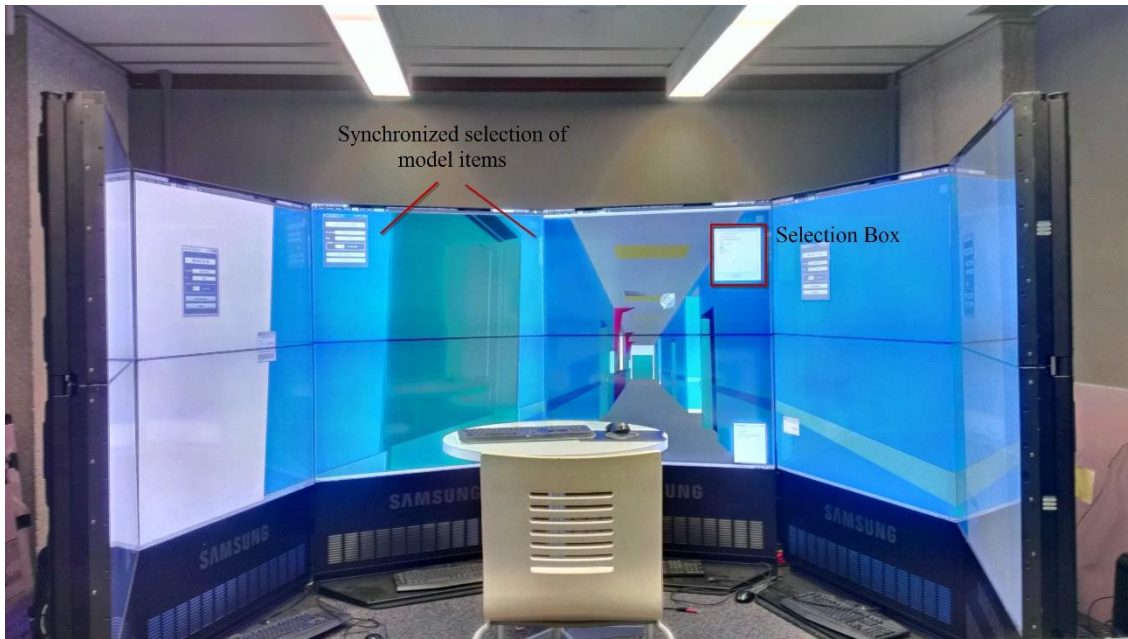


Figure 6 User control and end result

View existing selection sets within the 3D Model and click on a specific set to highlight them on all the computers. With the selection in place the user can manipulate the selected model items by either hiding them or by overriding the opacity of the selection. He also can undo any of the changes made by him.

Once a change is made relevant information is sent to the clients over the network to ensure consistency of the 3D model over all the computers. Figure-6 shows the intended result from software development after incorporating it into the BIM CAVE.

#### 4.3.2 Client Application

It is also a standalone application like the server. Previous versions of the BIM Cave application received data packets sent by the server. It would update the camera position and orientation if the information from the server is regarding the camera and

it would perform the timelining instructions if the data packets contain that information.

This research also adds the following additional functions to the client application.

- The data packets received by the client contain information about the kind of function performed by the server.
- Once these packets are received they are sorted to identify the function performed on the server and it is executed as soon the necessary information is gathered.

#### 4.3.3 BIM CAVE Application Interface

The BIM CAVE's server and client application should be installed in the server and client computers respectively. The server and the client application have a button 'Start Navisworks', which will let the user select a Navisworks file and open the same. Essentially all the six computers run a separate instance of the same Navisworks file and only their views and stage of construction in 4D construction sequence are synchronized using the BIM CAVE application. It is highly important to make sure that the files that are opened in the server and client computers are the same to have a meaningful view across the screens. The 'Connect' button in the server application opens the port to allow the clients to connect with the server. The server application has a textbox that gets the port number input from the user. The default value for the port number is set as 8000 for both the server and clients. The server shows a status message indicating whether the clients are connected or not. The five buttons in green shown in the Server application Interface controls timelining. Figure-7 shows the server BIM CAVE server application interface. The last two rows of buttons perform the selection and

manipulation functions. The combo box in the penultimate row lets the user adjust the opaqueness of the model items.

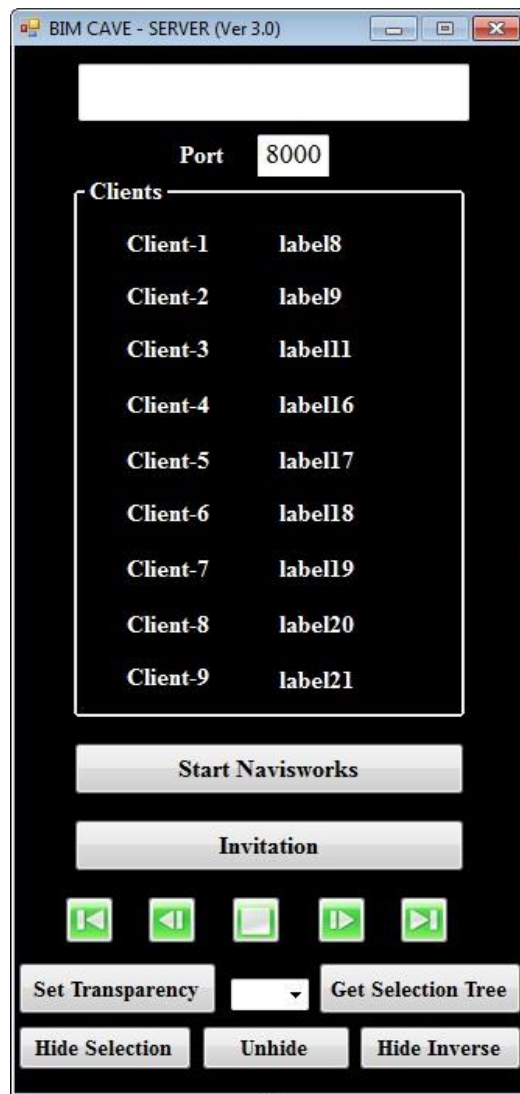


Figure 7 BIM CAVE: Server Application

#### 4.3.4 The Client application

The client application has a textbox to get the IP address input from the user. The server computer's IP address displayed in the server BIM CAVE application should be entered in the textbox and the port number should also be same as the server. The 'Connect' button in the client application will establish a connection between the server

and client computers. Figure-8 is a screen shot of the user interface of the updated client application. It has a dropdown list box that lets the user specify a camera rotation angle for the clients, which is dependent on the orientation of the screens. If the connection is established, the label on the application changes to 'connected' status.

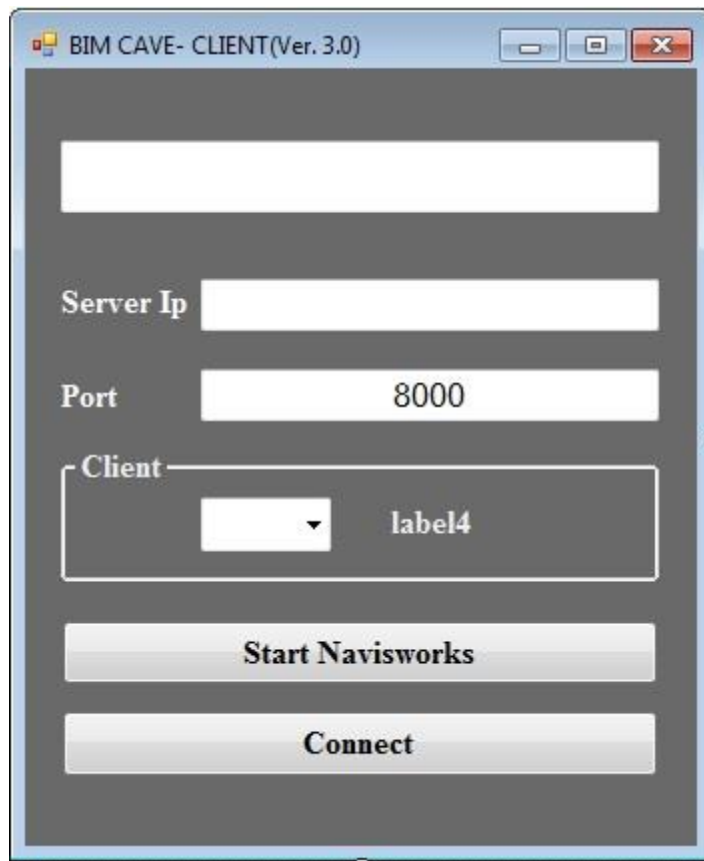


Figure 8 BIM CAVE: Client application

The operating instructions of the BIM CAVE application are explained in the following steps:

1. Using the 'Start Navisworks' button in the server and client BIM CAVE application, the same version of Navisworks file is opened in the server and client computers.
2. After opening Navisworks, the server computer's IP address displayed in the

Server BIM CAVE application is entered in the textbox of the client BIM CAVE application.

3. The server computer should be made to allow the client computers to connect to it by clicking the 'Connect' button in server BIM CAVE application.

4. The clients are then connected to the server by clicking the 'Connect' button in the client BIM CAVE application.

5. Once the clients are connected, the angles of rotation for clients are specified in the drop down list box of the respective client application.

6. In order to control the construction sequence and synchronize the stage of construction across server and client computers use the buttons in green as shown, but before using them the Navisworks Applications in all of the six computers should be changed to simulation mode.

7. Additional selection and analytical functions of model items are found on the last two rows of the server application.

#### 4.3.5 Server-Client Algorithm

The server client algorithm used in the first version of the BIM CAVE is used for this research. It is developed using .Net sockets which facilitates communication between the server and the two clients. The server application extracts information regarding the position and orientation of the camera and applies an algorithm to it. This results in the input about the camera that needs to be fed to the clients. Similar sequences of events take place to execute the timelining feature of the application.



Unique data packets identifying the function are generated by the server and the client receives, identifies and executes that specific function. The client computers need to have good configurations supported by a high bandwidth network as the communication process is asynchronous. This means that the server doesn't wait for the client to finish responding to an instruction (Ganapathi Subramanian 2012). This is also a multithreaded process in both the applications. The server and the client listen and send information to each other simultaneously.

#### 4.3.6 Navisworks API Algorithm

The Navisworks API algorithm deals with the interaction of the BIM CAVE application and Navisworks (Ganapathi Subramanian 2012). The API algorithm is different for the server and the client computers. C#, the programming language that was used to develop the applications is an event driven language. In other words when an event occurs, such as the click of a button, a specific function can be executed. This mechanism is employed in the BIM CAVE application. An Event Handler is assigned to perform a function each time an event is triggered. All of the functions that are needed for this research are accomplished via plugins.

Four of the events i.e., Hide, Unhide, Hide Inverse selection and overriding the transparency of model items are executed by assigning the corresponding event handlers unique numbers which are matched against the numbers assigned to the plugins. When a specific Event Handler is triggered the appropriate plugin is executed and thus the specific task is performed. As the function is performed on the server the

unique number is communicated to the clients. When the client receives the number it too executes the same plugin to produce the desired effect.

Although selecting model items in the server and updating them in the clients is achieved through plugins, they follow a slightly different procedure. Every model item has a unique ID in its properties. This is utilized to identify them. When a selection is made all of the IDs are collected and saved to text file (*Test.txt*) on the server computer. These IDs are then communicated to the clients. On receiving these IDs a search function is deployed to identify the model items. Once they are identified the selection is updated. It is to be noted that unless a selection is made in the first place the manipulative functions will not produce any discernable change.

#### 4.3.7 BIM CAVE Mechanism

The BIM CAVE application developed for this research integrates the hardware and the software components to achieve an immersive virtual reality environment. The BIM application executes three algorithms Server-Client, Navisworks API and Mathematical Rotation in a particular order to achieve a coherent view in all six walls. The following steps explain the working process of the BIM CAVE application developed:

1. First, the Navisworks API algorithm is executed in the server BIM application. The API algorithm will collect the camera parameters such as *position*, *view direction vector* and *up vector* whenever the current view of the camera changes. It also captures the button pressed in the BIM CAVE server application interface and assigns a number to it. In addition to that, it generates a text file on the server containing the IDs of the selected



Figure 10 BIM CAVE: Synchronized View



Figure 9 BIM CAVE: Unsynchronized model view

model items. While figure-10 is a photograph of the BIM CAVE before the computers are communicating with each other, figure-9 is a photograph after they start communicating.

2. Once the server's camera parameters are generated, relevant camera parameters such as the position, the axis and angle of rotation for each of the clients will be gathered and sent to the client.

3. The Server-Client algorithm will be used to transfer the data packets containing the axis, angle of rotation, and unique number generated corresponding to the button pressed in the BIM CAVE server application interface to each of the clients connected with the server. It also sends a stream of information containing the IDs of the selected model items. Figure-11 illustrates the synchronized selection of the new BIM CAVE application.



Figure 11 BIM CAVE: Synchronized selection

4. Clients receive the data packets sent by the server using the Server-Client algorithm.

5. After receiving the data packets the rotation algorithm will be used by the clients to update their camera position with respect to the server, synchronize the stage of construction during 4D construction sequence, update the selection made by the user and execute model manipulative functions in order to achieve an immersive view using

the Navisworks API algorithm. In figure-12 we can see the changes made uniformly across all the systems.



Figure 12 BIM CAVE: Uniform change of selected items

Figure-13 is an illustration of the BIM CAVE mechanism using a flow chart approach.

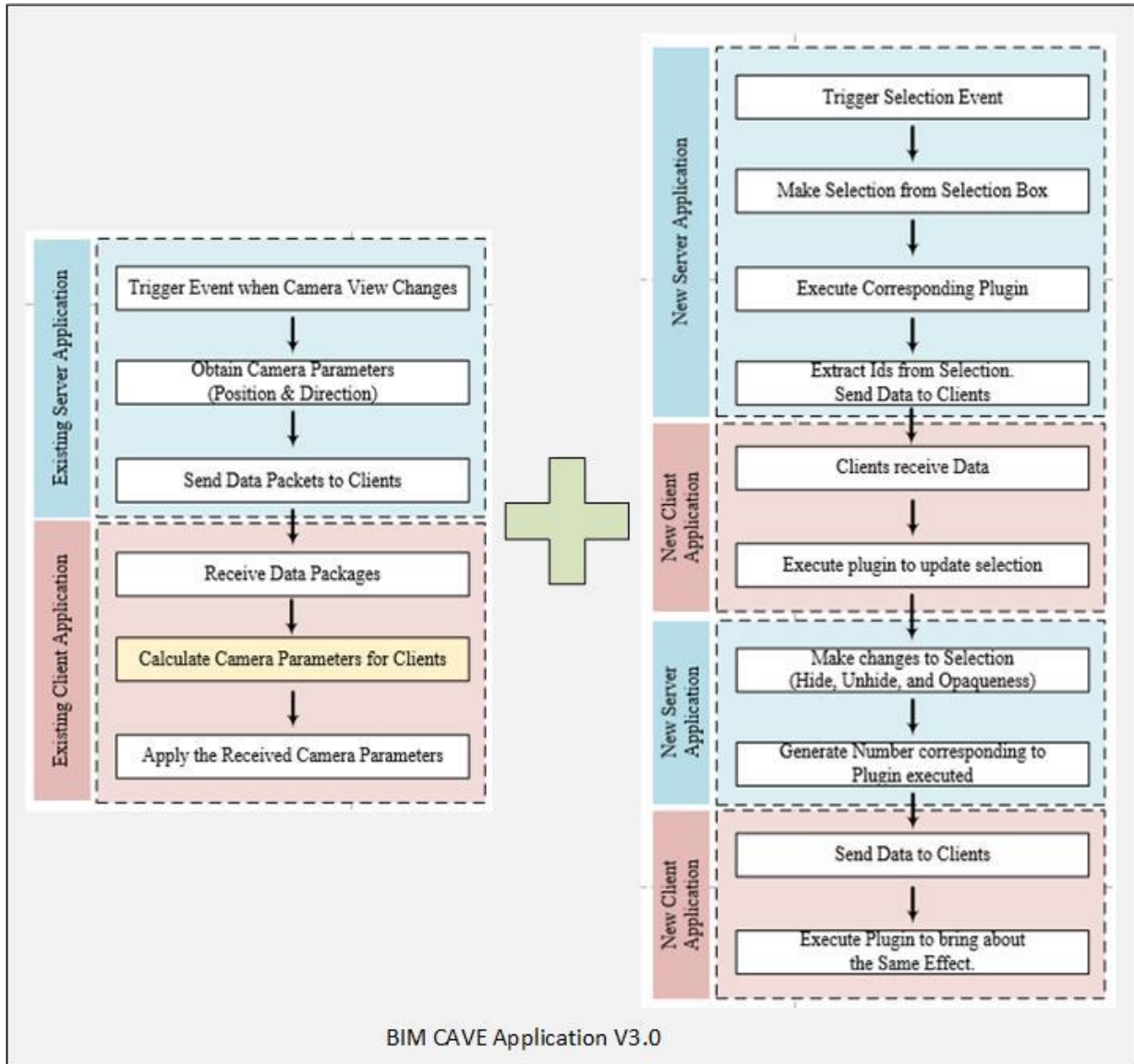


Figure 13 BIM CAVE: Working mechanism

#### 4.4 Challenges Faced

The additional functionality needed for this research can't be achieved in one single step. So it needs to be broken down into many sub-problems. The fundamental sub-problem, a two-step process, lies in the identification of a model item and simultaneously updating the selection in all the computers on the network. In order to achieve this it is essential to identify an ID unique to a model item. Navisworks displays IDs in the properties window of a model item.

Although Identification was achieved quickly, it was the simultaneous update in all the computers that turned out to be bigger challenge. If the computers were all connected to a central database, any change in the database would result in a real time update in all of the computers. As this wasn't the case with the BIM CAVE system an alternative had to be put in place.

The alternative was to generate a file on the server computer which contain identification information of the selected model items. After the file is generated its contents are communicated to the clients through the communication system already in place. Once the clients receive the information from the server the selection updates are then affected.

The implementation of these methods in the server and client applications was another challenge. Automation assembly doesn't provide classes to achieve the methods directly. So, plugins for each step of each sub-problem had to be developed. This resulted in a total of six plugins. This information wasn't readily available and a lot of time was spent on trials and debugging.



## 5. DATA COLLECTION

Phenomenological study is the research methodology that has been employed to validate the new application that has been developed. Interviews of the subject matter experts (SMEs) have been audio taped so that they can be transcribed and analyzed to understand their perception. This had been done to not interrupt the participant which could otherwise lead to incomplete information exchange between the interviewer and the interviewee.

A typical sample size for a Phenomenological study is from 5 to 25 individuals, all of whom have had direct experience with the phenomena being studied (Creswell 2007). Five participants were interviewed who were professionals from the AEC industry with experience in BIM, virtual reality systems, and project planning. The five participants of this study include a Technical services engineer, a Senior Program Manager and Architect, a BIM engineer, a VDC Manager and a VDC coordinator, representing different companies. In order to protect the privacy of the participants, no personal information was used for identification purposes. Pseudonyms and codes will be assigned to a participant and they will be used to identify the participants. Since, the results from this study is based on the feedback given by the five participants, their credibility is a major factor for obtaining reliable results.



The qualifications of the participants of this study are

1. Technical services engineer: Interviewee 1 has about 5 years of experience in the construction industry with BIM coordination, estimation and bidding new projects.
2. Senior Program Manager and Architect: Interviewee 2 has about 15 years construction experience in program management and architecture. He has a lot of experience in utilizing and implementing BIM over a wide range of projects.
3. BIM engineer: Interviewee 3 has about 4 years of experience working as a BIM specialist. He is involved in creating and maintaining 4D schedules and also coordination activities.
4. VDC Manager: Interviewee 4 has about 8 years of experience with BIM in the construction industry. His specialties include 3D site coordination, 4D scheduling, 5D estimating.
5. VDC coordinator: Interviewee has recently started working in the construction industry but has a doctorate degree from University of Austin and has worked on three projects towards her degree.

The following questions were asked of every participant:

- Describe your experience inside the BIM CAVE?
- Do you think the current BIM CAVE setup might in any way help in solving design and/or coordination issues of any kind?
- Can you think of any other advantages or disadvantages with this current setup?
- Can you think of any ways of improving the existing setup?

These questions helped to know the participant's view about the efficacy of the new application in issue resolution and visualization of 3D models in an IVR environment.

The advantages and disadvantages of such a system were also highlighted. Appendix A - contains the transcripts of all the interviews conducted.

## 6. RESULTS

The audio tapes of the interviews were used to transcribe the statements of the participants and the information was analyzed to understand the efficacy of the new application. This chapter documents the findings of the interviews, gauging the value of the new application and also identifying its advantages and disadvantages.

The transcripts were analyzed and grouped based on the following:

1. Their experience of utilizing the new feature added to the existing application.
2. The advantages of the available new features.
3. The likely disadvantages of the new setup.

### 6.1 BIM CAVE with added functions

The interviewees were introduced to the CAVE environment to familiarize themselves with it. They were then given a demonstration of the new developed feature. After this they were questioned about their experience and the impact of this new feature.

Interviewee 1, Technical services engineer, described it as a perfect medium for owners and subcontractors to visualize the layout and everything that they would like to see. He stated that at times one spends a lot of time trying to get a specific view in tight rooms. Now, with the ability to hide or override the transparency it will be much easier to spot issues. He was also of the opinion that it had really good immersive aspect to it.

Interviewee 2, a senior program manager, thought that it helps him understand and visualize different components inside a building in a much better way. He also stated that the relationships between these components are much better in this environment and therefore this is ideal to identify potential conflicts. The ability to change the transparency and remove items from the line of sight can be effectively used in design and construction meetings according to him. This will save a lot of time and eventually the cost of construction.

Interviewee 3, a BIM engineer, He said that with this kind of environment it could be really useful in exploring a building and see what's around you. He also said that with one large screen it's hard to see what's around and the user might lose perspective. According to him it will have a positive effect.

Interviewee 4, a VDC Manager, thought it would have a positive effect as it would feel more natural looking at a space.

Interviewee 5, a VDC coordinator, thinks that it will be helpful for the owners, superintendents to get a good sense of what the space will look like. She believes that letting people, who aren't familiar with virtual models, use this might make them appreciate it more.

## 6.2 Advantages of the new setup

Interviews with industry professionals from the construction industry revealed the benefits of the added features in the new BIM CAVE system. They can be summarized as follows

- In coordination meetings it can serve as an effective communication tool.
- Helps subcontractors in visualizing various components and their relationship with other systems.
- It also aids the subcontractors in identifying the issues in a much better way.
- Since issue identification is much faster it saves a lot of time and money.
- It could be also used as learning tool for people who aren't familiar with 3D models.

### 6.3 Limitations of the new setup

The interviewees also shared their opinions regarding the disadvantages and limitations of the new setup.

- The application relies heavily on the server and the control is too centralized as a result of which some aspect of fluidity is lost.
- The CAVE system in its current configuration seems like it's oriented for a single person rather than a group of people due to its enclosed configuration.

## 7. CONCLUSION

This section gives a summary of the research that has been undertaken. It briefs the research problem, methodology and the results. A subsection is dedicated to the future research that can be undertaken.

### 7.1 Research Summary

This research developed a new BIM CAVE plugin application that can hide certain building components in the 3D model, and then tested its effectiveness.

One of the limitations of the previous BIM CAVE application was its inability to synchronize selection of model items over all the screens and view MEP and other systems of a 3D model in isolation. This resulted in partial disengagement and loss of immersion when visualizing a 3D model.

The new application was validated by inviting five construction industry professionals to test and use it. Later, interviews of the research participants were conducted to obtain their views regarding the effectiveness of the new BIM CAVE plugin application.

The interviews revealed that it has a positive impact on owners and MEP subcontractors in visualizing various components that make a 3D model and understanding the relationship between them. The research participants were of the opinion that the use of the new BIM CAVE plugin application will result in identifying and solving issues in much lesser time, effectively communicate design ideas and educate trade workers on using 3D models to their advantage.

The research participants also highlighted a few limitations and improvements that could be made. Some of them felt that the current BIM CAVE is optimized for a single user rather than a group. A couple of the participants felt the use of gesture controls could be more effective.

In conclusion, the new application is effective and has a positive impact.

## 7.2 Future Research

Summarizing the suggestions of the research participants, the possible future research ideas on the BIM Cave are as follows:

1. Simplify and in turn improve the interaction experience by utilizing gestures as input devices to control the setup.
2. The ability to pick and move things to see if things can fit in some spaces. This could come in handy for interior designers and subcontractors who can plan and manage labor, material beforehand.
3. Section views of 3D models, which are vital for coordination activities, are limited to just one computer and aren't supported in this version of the application.
4. Add the ability to override the color of the model items and provide first time users with a scale for better understanding.
5. Multiple curved screens instead of the current segmented screens can be tested for much better immersive experiences.



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## APPENDIX A

### Interview Transcripts

#### Interview 1

Interviewer:

Can you describe the BIM Cave experience? What was it like?

Interviewee:

As far as the, or the BIM coordination that we had and with the owners and the architects that we had in here as we discussed earlier the solid walls...everything the way it worked it was perfect uh...it gave it nice visual to the owner as far the layout of everything he likes being able to see everything as far as where the equipment was going to go uh... knowing what rooms were where? How they were laid out? And as far as the immersive aspect of it they enjoyed seeing it wrap around I think liked everything about that. Trying to think of anything else they said. No, I mean it worked perfect as far them seeing they felt comfortable with it, they liked what they saw uh I think the effect with the solid walls we were talking about earlier it was ideal for the people we had in the room it was exactly what they wanted to see.

Interviewer:

The new application that I've demonstrated uh... How do you think , if you had a chance to use it in a meeting like this , how do you think it would affect the decision making process of say your clients or owners or subcontractors such as MEP sub-contractors?

Interviewee:

I think for the subcontractors it would be perfect. As far as the transparency aspect and seeing the interior walls being transparent and the ceilings being transparent especially for some of the tighter rooms cause a lot of times you will spend a lot of time trying to get oriented and with this setup, the way it is setup you don't waste as much as time trying to get to that view , I can walk down the corridor and immediately see that we've got an issue with a beam , a beam and a beam and then the subs can merely go looking at that and then if how you have it setup to with the hide select as far as I select the ceilings and hit hide that's really quick cause then I can grab duct quickly move it at where I need and go back grab the ceiling with your selection sets and then hit this , I'm guessing this un-hides and then go right on. So, yeah it's from what we were saying before when I was originally was thinking just one computer when you've got six running that it streamlines the whole process for something that would be extremely hard and laborious to do this makes it a lot easier. so I would yeah I mean yeah for the horsepower your pushing as far the computers are concerned the data that you're pushing through there adding it's I'm not being insulting it seems like a simple feature but what it takes to get there it's impressive.

Interviewer:

You did mention like I mean .do you think that there is any disadvantage with just relying on just one computer .Everything that needs to be done is through the server do you think with this setup it might be disadvantageous in any way? Or can you think of any disadvantages of this setup?

Interviewee:

I could say yes or no. The advantage of it I think would be that you have once central spot to look at and your brain is just going to be on one screen that's all you have to worry about. I guess the only disadvantage, if I would say there was one cause even on my stuff when I'm working it with four screens on one computer I'm still basically the confines of this one screen. so even if I've got my saved view points and I've got my comments section below and they're asking the orientation map. I've got all that setup on my screen but it's still one screen its centralized and I'm thinking off the cuff here but as far as that goes it's nice to be centralized when you have an array like this but it kind of gets lost cause why do I have to focus on one main computer it's almost like why can't it be fluid as far as I can spin in my chair and look at that screen for another detail and then it's...uh... don't know if it makes sense it's almost like the whole thing just being one cohesive main screen as far the user is concerned like you know that this is where everything is happening as far the computer is on the other side but if I came in as a user and I'm not used to focus cause you know everyone has a different way of using something cause you may come and be like I want this here and this here and someone else wants everything there . So it's like no matter where you look that's your main screen so if we came in and look at the hallway and your like well I want to see that Fire proofing cabinet over here instead of spinning like you just go over there then it's like cause it's this is the environment.

Interviewer:

Is there a better arrangement of the screens? Any suggestions that you can think of?

Interviewee:

I think as far as for one cause right now it's geared I mean it's setup for one person to use it. so , think for one person going thru like if we were doing a go to meeting with a bunch of people this would be kind of lost because they've got one screen and that's the limitation to go to as far as it can show only one screen that's what they're designed to show. Um even if they looked at it they might see all of this but it's going to be flat and may be warped I don't know.in that sense for one person it might be perfect but for a group of people they're still outside the 3D sitting here and if they've got people in front of them they're looking at one screen.

Interviewer:

I noticed that a person sitting towards a side doesn't get the complete picture and she's open to one section and I'm not really sure if this is giving a warped picture and it reflects reality in a way?

Interviewee:

I would say it's not warped cause I'm looking I'm Just following that bump rail going all the way down and it's pretty much in perspective and its cool for me .I mean this is how you would see a building it's like if I was sitting in the hallway looking down and I look sideways and you have a bit of effect with the screen but that's just physical but as far as the display the way you guys have everything as far as the camera views inside the programs its perfect. you can tweak it forever but where it's at now this view it's like, like we were saying as far as which screen like that's the main screen but as far as where I'm looking at right now it make sense like that would be a normal perspective view

where it gets warped you know like a fish eye kind of look. It is setup right. So, I think for someone sitting here I'm still getting four screens of view. So there still not completely outside the realm cause someone's sitting outside and behind the user they're losing the outside four screens and getting just two. Your center node is here cause I think if you could move it here and push these out and your periphery is here and for the person sitting here like you know that's as far he can turn and see but don't have to see what's behind me. If you can push that out, push that out a bit more and your periphery is here when you can turn a bit you can see a bit behind you.

Interviewer:

Do you have any suggestions?

Interviewee:

For group meetings probably change the configuration to accommodate a lot of people so that they can see whatever the central driver is seeing. This way all can be on the same page and have the same configuration and not feel left out of it or feel confused. This whole immersive view didn't help me to view the platform space cause I couldn't see it enough which is what we were talking about cause I had to be above it to see it and with the section cut that kind of got lost but that the only way I could've seen that. so that one thing I guess if there is a tweak to look at later on is when we do that section view and it shows up all the way around.



## Interview 2

Interviewer:

Can you describe what you just saw?

Interviewee:

The impression that I get from the BIM CAVE is that it gives me a better understanding and visualization of all the major building components besides the not only showing the HVAC but the relationship between the HVAC units , the structural items and the major components of the arch features such as the interior walls doors and some of the plumbing fixtures like the water fountains .So, it gives me a good understanding of the relationship and also potential conflicts that I may have during the design process if you have any conflicts between major systems . So that's the biggest advantage from this setup.

Interviewer:

If you had a chance to use this updated feature in a coordination meeting, how do you think it can affect the whole process?

Interviewee:

The major grouping that I see and also the transparencies that are setup for the model , I think it can be effectively used in a design or a construction meeting by quickly accessing the major components behind some of the major systems rather than pick and choose each of the units individually you can pick entire groupings of systems uh as a group and set the transparencies and gradation understand the relationships even better by setting various and different levels of transparency in a meeting and then also

the actual grouping and the creation if the trees uh are also a big advantage if you can delete an entire system like an HVAC system or a structural system to see another hidden condition it's a big advantage because it means the meetings can go quicker , save time and make major decisions in any particular systems a lot faster. So, it expedites not only meetings but design decisions it can impact eventually the construction cost of the project.

Interviewer:

Can you think of any disadvantages or advantages of this setup?

Interviewee:

I can't think of too many disadvantages of what I'm saying or how it's being used. However some improvements could be made may be a little bit more level of detail may be needed. A minor disadvantage maybe a mix of colors can be sometimes confusing, the colors used and the weight lines may be better defined to give a better understanding of the relation for example the color you may have for the doors, adjoining walls you use the same gradations or same hues or colors. so I think the use of colors is important to get a better understanding , a disadvantage can be it's not necessarily here ...but if you don't select correct colors for hues and chromes of the colors it could be somewhat confusing very easily .

Interviewer:

Do you have any suggestions?

Interviewee:

The major suggestion that I have is to have a better connectivity b/w the screens where you have an immediate interaction when you select groups(selection sets) whether then do it manually from screen to screen that's the obvious one because I don't think you that , hopefully you're working on that . So from an owner's point of view in a meeting you don't end up individually selecting some of the components on all these computers and items within a tree are connected to the tree simultaneously like a virtual studio if you will. another thing you can strive for is also as strange as it may sound in your BIM model have some human figures to give the person and the model some scale and sometimes you don't know if you're talking about doors that are 12' high or 10' high or 15' or 20' by giving it some kind of a human scale will give the user some better understanding of the scale of the model. If I see a person I'll think about 5.5' or 6' and if I see a door then I'll know that it must be about 7' or if I see a person down here then I'll know that's probably a 12' door.

### Interview 3

Interviewer:

Can you describe the BIM CAVE experience?

Interviewee:

Passing selection sets from a master Navisworks application to slave applications on client servers so you can hide and show or set transparency and probably override colors and do all sorts of things with it .Just have to have the selection sets passed I guess that's the key point.

Interviewer:

If you had a chance to use this updated feature in a coordination meeting, how do you think it can affect the whole process?

Interviewee:

That's kind of a tough question, most of the time in my meetings we use just one Navisworks app mainly because we have only one large screen with a bunch of people in the same room but in an environment like this I could see it being really useful to explore building and sometimes it's kind of hard to see what's around you and get an idea of what things actually look like cause from one screen or large screen perspective you lose a lot. I mean if we had a way to different application on client- server or some sort of slave machine ...yeah it could be pretty useful as we don't have that we don't do that but yeah it will be pretty useful. I think it will have a positive effect.

Interviewer:

Can you think of any disadvantages or advantages of this setup?

Interviewee:

Definitely advantages...umm...if you're going to change anything on the screen you want it done throughout so definitely advantages there. The only comments I really have are about the interface, may be make it easier for a normal user or make it a...uh...I guess make it a default for anyone who is using it. It's more of a seamless transition .when you select the object and hide it does it for you instead of having to go to a separate interface than normal. Does that make sense?

So if I select a wall and hide it, it should hide everywhere instead of having to go to the uh the server interface and hide it.

Interviewer:

Does that mean you want it to be done from the client as well?

Interviewee:

No not from the client. Like when you connect all the clients to the server and you go through the menu and you're hiding things and changing transparency from that menu you would be really helpful to have it done from the normal menu like if you didn't have the clients. Just make the menu in the background, that's should be easiest thing. I'm sure that'll happen somewhere in the future...It's just a menu change.

Interviewer:

Do you have any suggestions to improve this setup?

Interviewee:

Any changes would be just to expand it. Do more than transparency and hiding and move to things like overriding color uh ...Transformations and things like that? If you can already do hiding transparency then that's just another command that you can do it.

#### Interview 4

Interviewer:

Can you describe your experience of the BIM CAVE?

Interviewee:

Multiple screens wrapping around my vision while I looked at a finished corridor and the MEP exposed behind transparent walls and hidden ceilings.

Interviewer:

If you had a chance to use this updated feature in a coordination meeting, how do you think it can affect the whole process?

Interviewee:

I think it would have positive effect and it would feel more natural looking at a space and I think that adding in a treadmill would be great so you can just naturally walk around and then from a user interface standpoint of things taking and using just gestures to locate things is similar to real life as possible would be helpful for getting the most participation.

Interviewer:

What are the advantages and/or disadvantages with this setup, if there are any?

Interviewee:

So Although the feeling that you would get when you're looking around the space feels intuitive the reliance on connecting multiple servers and just user interface with the mouse currently is hard to use so to have the user interface go away just to visual and then you're actions create the changes on the screen. No interface would be the most

positive I think. Cause you have this very easy to comprehend view that may just blow people's mind when they see all this. More tech savvy interfaces.

Interviewer:

Can you think of any improvements that can be made?

Interviewee:

Application where if there are funds available where they actually have a curved screen will be helpful. we are showing a segmented curved screen .This might be an application where that makes sense is to have multiple curved screens uh...and the more you can eliminate the bezel the better but that's mostly hardware improvements and I think that could tie perfectly the angles . right now it's 40 degrees angles understanding the perfect focal point and then being able to adjust so that's it's exactly how you want it so you don't have any those breaks where you get from screen to screen.



## Interview 5

Interviewer:

Can you describe your experience of the BIM CAVE?

Interviewee:

I saw twelve screens and six servers connected showing me and immersive environment within a BIM model and I saw a corridor and the rooms at my left and right hand side and a screen showing on my back. I think that's the view that you won't get when you're viewing a Synchro screen.

Interviewer:

If you had a chance to use this updated feature in a coordination meeting, how do you think it can affect the whole process?

Interviewee:

I think it'll be helpful to show the owners what the environment with the space will look like when it gets built and also it would be good to show the superintendent especially those ones for who aren't familiar with the virtual model and to like making environment as real as possible so that he can appreciate this and get to use it more and I think it will be good to have the future users or attendants to see this space to have them visualize how they can utilize the space or for interior designers to see what kind of art they want to hang . So this kind of feeling would be helpful to them I think.

Interviewer:

What are the advantages and/or disadvantages with this setup, if there are any?

Interviewee:

Similar answer though. I think that the challenge is to seamlessly connect the servers and have the program work smoothly and also um...from the technical side it's a bit challenging to apply.

Interviewer:

Can you think of any improvements that can be made?

Interviewee:

I think, if it's possible I'll prefer a more intuitive interaction with the system. If it's possible we can use gesture control and like to pick things up and down and see if I can move the light out without hitting anything...something like that. If this equipment will fit in the door way or in that space, we can try it in this environment.